

Revisiting the theoretical DBV (V777 Her) instability strip: the MLT theory of convection

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Abstract. We reexamine the theoretical instability domain of pulsating DB white dwarfs (DBV or V777 Her variables). We performed an extensive g -mode nonadiabatic pulsation analysis of DB evolutionary models considering a wide range of stellar masses, for which the complete evolutionary stages of their progenitors from the ZAMS, through the thermally pulsing AGB and born-again phases, the domain of the PG1159 stars, the hot phase of DO white dwarfs, and then the DB white dwarf stage have been considered. We explicitly account for the evolution of the chemical abundance distribution due to time-dependent chemical diffusion processes. We examine the impact of the different prescriptions of the MLT theory of convection and the effects of small amounts of H in the almost He-pure atmospheres of DB stars on the precise location of the theoretical blue edge of the DBV instability strip.

1. Introduction

Variable DB white dwarfs (also called DBV or V777 Her stars) are g -mode nonradial pulsators with periods ranging from 200 to 1000 s. They are characterized by He-rich atmospheres, possibly contaminated with small impurities of H. Their pulsations are thought to be triggered by the $\kappa - \gamma$ mechanism acting on the partial ionization of He at the base of the outer convection zone. The observed instability strip of the DBV stars is located between $T_{\text{eff}} \approx 28\,400$ K and $T_{\text{eff}} \approx 22\,500$ K (Winget & Kepler 2008). All of the published stability analysis of DB models — see, for instance, Bradley & Winget (1994) and Beauchamp et al. (1999) — clearly indicate a strong dependence of location of the *theoretical* blue (hot) edge of the DBV instability strip with the convective efficiency adopted in the envelope of the stellar models. At present, there is no general consensus between different authors about what is the right convective efficiency of DB models in order to fit the observed blue edge. On the other hand, there exists an additional uncertainty in the definition of the temperature scale of the DB stars, and consequently in the location of the *observed* blue edge, due to the strong dependence with the convective efficiency adopted in the model atmosphere fits. Finally, another difficulty is the uncertainty in the surface parameters that results from the presence of undetectable amounts of H in the atmospheres of DB stars (Beauchamp et al. 1999). In this work, we explore the impact of different convective

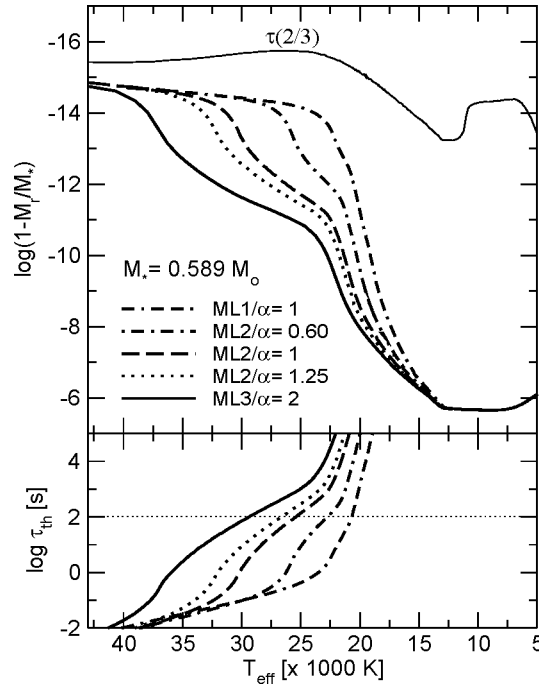


Figure 1. The extent in mass of the outer convection zone in terms of T_{eff} for different prescriptions of the MLT theory of convection (upper panel), and the run of the thermal timescale at the basis of the outer convective zone (lower panel).

efficiencies and of small amounts of H in the atmospheres of DB stars on the precise location of the theoretical blue edge of the DBV instability strip. We employ the Mixing Length Theory (MLT) of convection to model the outer convection zone of our models. We also examine the dependence of the blue edge with the stellar mass. To this end, we perform fully nonadiabatic pulsation calculations of up-to-date DB white dwarf evolutionary models with a wide range of stellar masses.

2. Stellar structure, evolution and pulsation modeling

We employ a new set of fully evolutionary DB white dwarf models that descend from the post-born again PG1159 models (Miller Bertolami & Althaus 2006). Specifically, we employ the LPCODE evolutionary code (Althaus et al. 2005) to compute the evolution of PG1159 models (H-deficient, He-, C-, and O-dominated atmospheres) towards the DB regime (almost He-pure atmospheres) taking into account the time-dependent microscopic diffusion of ^4He , ^{12}C , ^{13}C , ^{14}N , ^{16}O and ^{22}Ne . The metallicity is assumed to be $Z = 0$ in the metal-free He-rich envelopes and $Z \leq 0.02$ otherwise. The He-rich envelopes of our models are characterized by a double-layered chemical structure built up by chemical diffusion. We perform nonadiabatic pulsation computations of nonradial g -modes for $\ell = 1, 2$ with the code described in Córscico et al. (2006). We analyze the pulsation stability of DB white dwarf models with effective temperatures between 35 000 K and 17 000 K and stellar masses of 0.530, 0.542, 0.556, 0.565, 0.589, 0.609, 0.664, 0.741 and $0.870 M_{\odot}$. We model convection in the envelope of our models in the framework of the MLT theory. We employ the following prescriptions of the MLT, in order of increasing efficiency: $\text{ML1}/\alpha = 1$, $\text{ML2}/\alpha = 0.60$, $\text{ML2}/\alpha = 1$, $\text{ML2}/\alpha = 1.25$, and $\text{ML3}/\alpha = 2$, α being the characteristic mixing length (Tassoul et al. 1990).

3. Results

The evolution and extent of the outer convective zone of our DB white dwarf sequences during the DBV instability strip is shown in the upper panel of Fig. 1 for the different treatments of

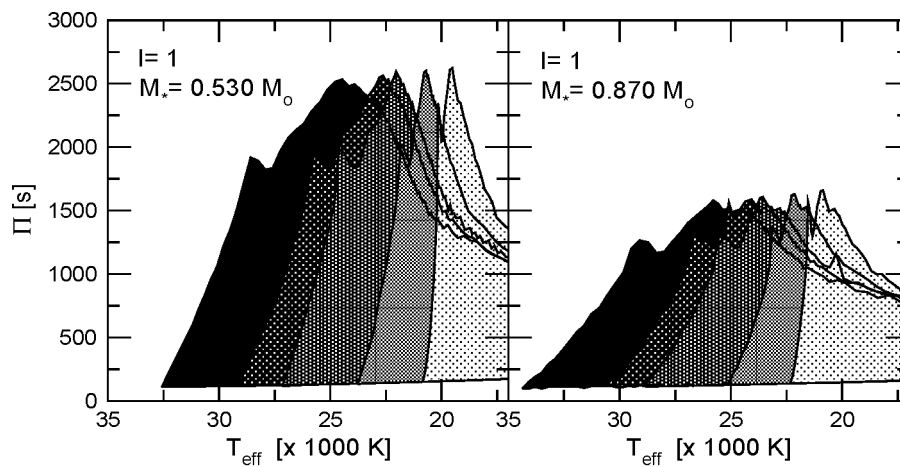


Figure 2. The instability domains of dipole modes for different MLT prescriptions (from left to right: $ML3/\alpha = 2$, $ML2/\alpha = 1.25$, $ML2/\alpha = 1$, $ML2/\alpha = 0.60$, and $ML1/\alpha = 1$).

the MLT. Note that the base of the outer convective zone notably deepens with cooling, being this effect more pronounced in the case of more efficient MLT prescriptions in the proximity of the blue edge ($T_{\text{eff}} \approx 29\,000$ K). In the lower panel we display the run of the thermal timescale at the basis of the outer convective zone. DB models are expected to become g -mode pulsationally unstable when $\tau_{\text{th}} \approx 100$ s. This would happen first for the highest convective efficiency ($ML3/\alpha = 2$) models. This is confirmed through full nonadiabatic computations.

Fig. 2 displays the instability domains in the $T_{\text{eff}} - \Pi$ diagram, corresponding to the sequence of $0.530M_{\odot}$ (left) and the sequence of $0.870M_{\odot}$ (right), for the different MLT prescriptions. On the basis of this figure, we can outline several trends: (1) there is a strong dependence of the longest excited periods with the stellar mass, being larger for less massive models; (2) the shorter excited periods, on the contrary, do not exhibit any dependence with M_* ; (3) regarding convection, there is no dependence of the longest (nor the shorter) excited periods with the particular MLT prescription adopted; (4) the blue edge is strongly sensible to the convective efficiency, being much hotter for efficient convection (that is, for $ML3$ and $ML2/\alpha = 1.25$); and (5) the blue edge is hotter for more massive DB models.

Now, we examine how our theoretical blue edges of the instability strip compare with the location of the observed pulsating DB white dwarfs. We consider the eight DBV stars considered in Beauchamp et al. (1999), plus the nine DBVs recently discovered in the SDSS (Nitta et al. 2009). We consider only the case of atmospheres devoided of H. Fig. 3 shows our complete set of DB evolutionary sequences (dashed lines) on the $T_{\text{eff}} - \log g$ diagram, along with the blue edge for the different MLT prescriptions. Note that there is a clear dependence of the blue edge with the stellar mass. It is apparent that only the $ML2/\alpha = 1.25$ prescription is able to account for the location of all known DBVs.

4. The effects of H on the location of the blue edge

At present, it is a well known observational fact that the atmospheres of DB white dwarf stars exhibit small traces of H, attributed mainly to accretion from the ISM. A modest accretion rate of about $10^{-19} - 10^{-21} M_{\odot}/\text{yr}$ would be enough to explain the presence of H in the DBs. The effective temperature of DB stars as derived from model atmospheres that contain H are considerably lower than in the cases in which H is neglected (Beauchamp et al. 1999; Castanheira et al. 2006; Voss et al. 2007). It is expected also that a non-negligible shift of the theoretical blue edge should result when the He-rich envelopes of the equilibrium models are contaminated with small impurities of H. To test this possibility, we have restricted ourselves to the sequences of $M_* = 0.530M_{\odot}$ and $M_* = 0.741M_{\odot}$. For these two values of the stellar mass, we have explored the cases in which $X_{\text{H}} = 0.0001, 0.001$ and 0.01 , corresponding

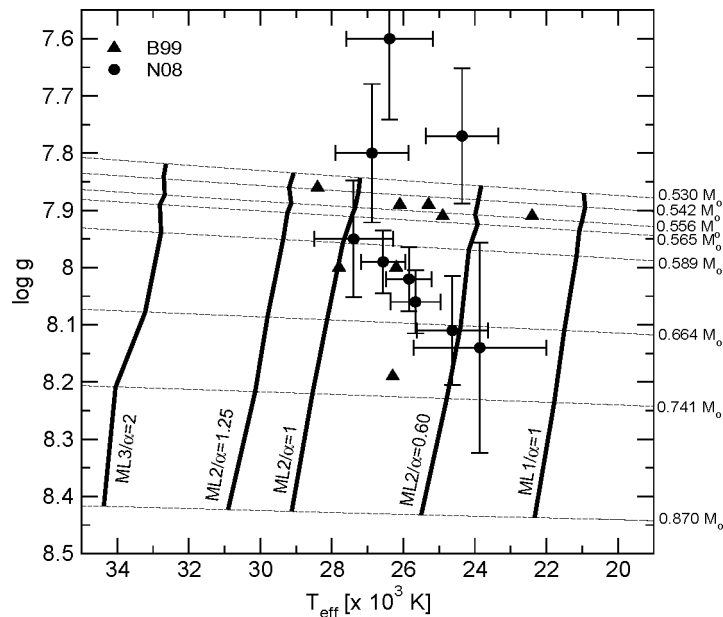


Figure 3. The blue edge of the DBV instability strip for different recipes of the MLT.

to $\log(n_{\text{H}}/n_{\text{He}}) = \log(4X_{\text{H}}/X_{\text{He}}) = -3.4, -2.4$ and -1.44 , respectively. We found that if $X_{\text{H}} = 0.0001$, there is no appreciable effects on the location of the blue edge. However, if $X_{\text{H}} = 0.001$ the blue edge is shifted to lower effective temperatures by ~ 800 K (for $\text{ML3}/\alpha = 2$) and ~ 300 K (for $\text{ML1}/\alpha = 1$). Finally, if $X_{\text{H}} = 0.01$ we obtain a shift of ~ 3000 K (for $\text{ML3}/\alpha = 2$) and ~ 1200 K (for $\text{ML1}/\alpha = 1$).

5. Conclusions

The results of the present work indicate that the best agreement between the location of the DBV stars previously studied in Beauchamp et al. (1999) with surface parameters from H-free model atmospheres, and the predictions of the nonadiabatic pulsation calculations is provided by the case of $\text{ML2}/\alpha = 1.25$. Notably, the T_{eff} and $\log g$ previously derived in Beauchamp et al. (1999) are obtained with model atmospheres that assume $\text{ML2}/\alpha = 1.25$. Our $\text{ML2}/\alpha = 1.25$ blue edge is consistent also with the SDSS DBV stars reported in Nitta et al. (2009), although their surface parameters are derived from model atmospheres with $\text{ML2}/\alpha = 0.60$. The present work constitutes the first phase of a thorough pulsation study (adiabatic and nonadiabatic) of DBV stars on the basis of a new generation of fully evolutionary DB models.

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